HIGH TEMPERATURE CHARACTERISTICS OF Ni_3Al ALLOYS AT VARIOUS TESTING CONDITIONS

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Abstract

Samples of Ni_3Al based alloys with hypo-stoichiometric composition Ni-24Al and Ni-22Al were directionally solidified at rates of 50 and 70 mm/h. The directionally solidified samples were used for creep tests at 900 °C. Testing was performed under a load of 200 MPa in an argon atmosphere. Due to the fact that materials of this type are used in demanding environments, the selected tests were also performed in argon saturated with water vapour. It can be concluded that the applied atmospheres have no significant effect on the creep behaviour of the studied samples. The Ni-22Al alloy exhibits longer times to rupture than the alloy Ni-24Al under the same testing conditions. No significant differences in the appearance and quantity of corrosion products on the surface of the samples were observed.

Keywords: Ni_3Al based alloys, directional solidification, creep, mechanical characteristics

1. INTRODUCTION

The nickel-aluminium system is the binary basis for superalloy compositions. As the level of aluminium added to γ-nickel increases, a second precipitate phase forms. This phase has a nominal composition of Ni_3Al, is designated the γ' phase, and has an ordered intermetallic $L1_2$ crystal structure. Formation of the γ' phase occurs in the solid state as the supersaturated solid solution of γ-nickel is cooled below its equilibrium solvus temperature. Hence, the precipitation and growth kinetics of the γ' phase are highly sensitive to the rate at which the alloy is cooled through the solvus temperature [1]. In nickel-based superalloys, the γ' phase [Ni_3(Al,Ti)] acts as a coherent barrier to dislocation motion and is a precipitate strengthener in the primary γ matrix. The shape and size of γ' phase can be precisely controlled by careful precipitation-hardening heat treatments. It is very important to take into account of the underlying micro-structure in order to develop a reliable constitutive model for predicting the strength and creep deformation behaviour of these alloys [2]. Nickel and nickel alloys have useful resistance to a wide variety of corrosive environments, typically encountered in various industrial processes such as in chemical processing petrochemical processing, aerospace engineering, power generation and energy conversion, thermal processing and heat treatment industry, oil and gas production, pollution control and waste processing, marine engineering, pulp and paper industry, agrichemicals, industrial and domestic heating, the electronics and telecommunication industries, and other [3]. Nickel alloys containing an intermetallic phase Ni_3Al are very interesting thanks to their properties. The Ni_3Al-based alloy has been modified with chromium, molybdenum, zirconium, and boron additions for obtaining a combination of improved strength and ductility properties [4]. Many various commercially used nickel-based superalloys exist nowadays - conventionally cast alloys, alloys directionally solidified or single crystal alloys. Development of individual types of alloys still continues, including the determination of mechanical properties at elevated temperatures (creep) [5-9].

2. EXPERIMENTAL PART

Ni_3Al based alloys were melted by vacuum induction melting. Samples were melted and cast under vacuum into the shape of rods with diameter of 10 mm. Chemical composition was verified by method of optical emission spectrometry. Samples of Ni_3Al based alloys with hypo-stoichiometric composition Ni-24Al and Ni-22Al were directionally solidified by Bridgman's method in corundum tubes with a specific angle. Two rates of directional solidification of 50 and 70 mm/h were applied. Flaw detection tests were performed on the samples in the directionally solidified state. Thus prepared samples did not contain any casting defects and they were used for determination of creep characteristics at high temperature. **Table 1** includes the nominal composition of alloys and rates of directional solidification r_{DS}. **Fig. 1** shows rod made from Ni_3Al alloy after directional solidification carried out with equipment Clasic CZ and Linn FRV-5-40/550/1900.

Table 1 Content of Ni_3Al based alloys

Sample No.	Content [at.%]	r_{DS} [mm/h]
A1	Ni-24Al	50
A2	Ni-24Al	70
A3	Ni-24Al	50
A4	Ni-24Al	50
A5	Ni-24Al	50
B1	Ni-22Al	50
B2	Ni-22Al	70
B3	Ni-22Al	50

Fig. 1 Rod made from Ni_3Al alloy after directional solidification

2.1 Evaluation of creep characteristics

The samples were used for creep tests at 900 °C. Testing was performed under a load of 200 MPa. For selected samples smaller load was used. The samples were tested in an argon atmosphere. Due to the fact that materials of this type are used in demanding environments, the selected tests were also performed in argon saturated with water vapour (20 %) and in working atmosphere. We chose working atmosphere as an atmosphere simulating oxidizing atmosphere conditions (saturated vapour approx. 80 %). **Table 2** includes high-temperature characteristics of Ni_3Al based alloys.

Fig. 2 shows a creep diagram of Ni-24Al alloys testing in different atmospheres. Due to the low creep life we chose timeline in minutes. It is evident from the dependence that evolution of creep is similar in argon atmosphere and also under the worst conditions in the working environment, which was saturated with water vapour. It may be stated that the no significant adverse effect of the atmosphere was proved. No significant differences in the appearance and quantity of corrosion products on the surface of the samples were found after the creep. The Ni_3Al based alloys without alloying elements did not show any significant corrosion damage of the surface.

Table 2 High-temperature characteristics of Ni_3Al based alloys

Sample	Atmosphere	Load [MPa]	Time to rupture [min]	Elongation [%]	Rate of secondary creep [s^{-1}]
A1	Ar	200	1350	33.0	4.43×10^{-6}
A2	Ar	200	1005	14.4	2.20×10^{-6}
A3	$Ar+H_2O$	200	520	23.1	7.20×10^{-6}
A5	$Ar+H_2O$ (work)	200	1335	32.5	3.16×10^{-6}
B1	Ar	200	11230	12.9	1.66×10^{-7}
B2	Ar	200	1870	19.3	1.95×10^{-6}
B3	Ar	50	197880	6.9	3.33×10^{-9}

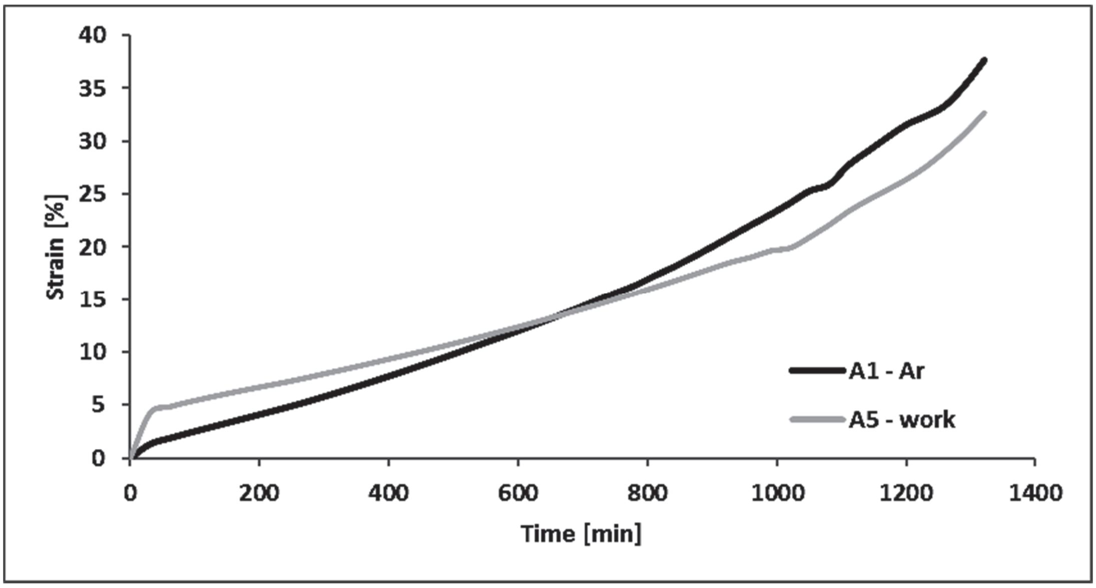

Fig. 2 Creep diagram - Ni-24Al, various testing conditions

Fig. 3 shows a creep diagram of the Ni-24Al and Ni-22Al alloys. The Ni-22Al alloy exhibits longer times to rupture than the alloy Ni-24Al under the same testing conditions with the rate of directional solidification of 50 mm/h. The sample B1 showed very good creep characteristics. It may be assumed that the lower rate of directional solidification of 70 mm/h is not sufficient for achievement of the correct structure. The sample might have also been damaged during machining to a tension specimen, since this material is very prone to the occurrence of recess. **Fig. 4** shows the dependence of the alloy Ni-22Al under different loads. In view of the improved creep life the timeline is given in hours. It can be seen that the multiphase structure of these alloys containing network structure γ and γ', as well as precipitates of γ', is very favourable. Material exhibits improved mechanical properties at elevated temperatures. Time to rupture of the sample B3 under the load of 50 MPa is 3298 h and the value of the secondary creep rate is 3.33×10^{-9}. This value is in good agreement in comparison with the alloy Ni-22Al-1Zr, for which the value of the secondary creep rate was 8.3×10^{-8} under the load of 80 MPa and under the same temperature [10]. Comparison with the directionally solidified Ni_3Al based alloy IC6SX without expensive elements shows that this alloy had at testing at 980 °C/205 MPa lower ability of deformation as compared to our alloy B1. This single crystal alloy has 0.7 % creep strain after 100 h creep tests [6].

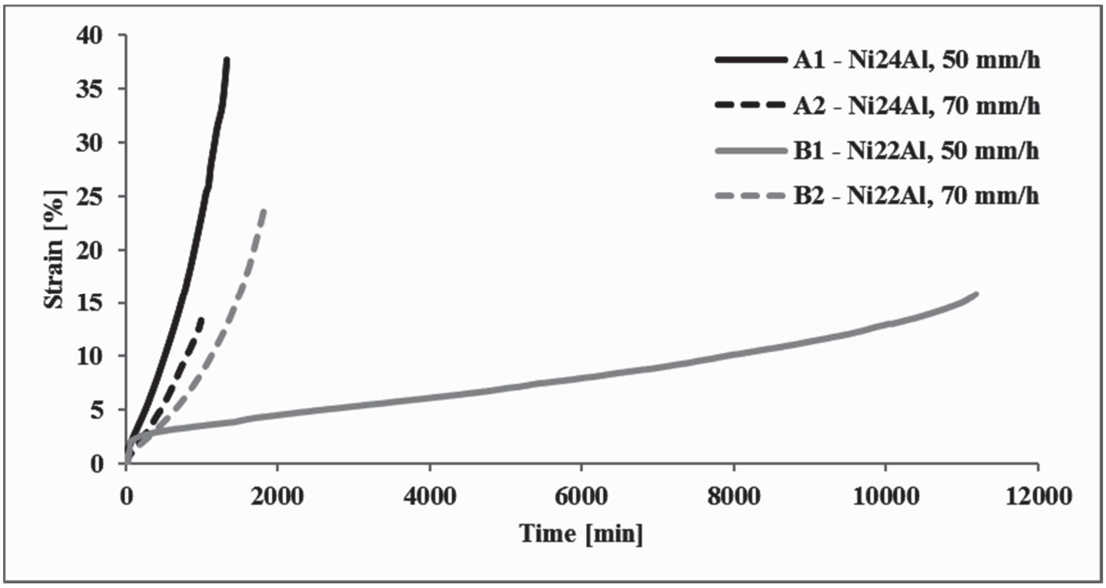

Fig. 3 Creep diagram - Ni-24Al and Ni-22Al, various content of Al and rates of solidification

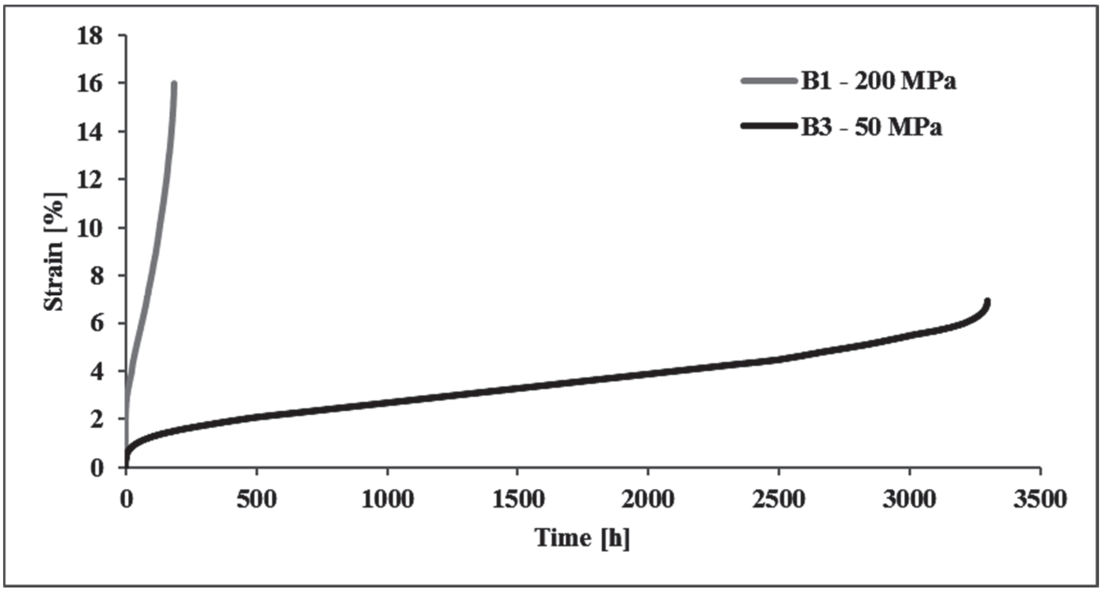

Fig. 4 Creep diagram - Ni-22Al, various loads

2.2 Evaluation of structural characteristics

Figs. 5 to 7 show macro- and micro-structures of the samples in directed state. Structural analysis was made on longitudinal and transverse sections of the samples. Evaluation of the structure and the phase composition was performed with an optical and an analytical scanning microscope. Typical structure of samples Ni-24Al was formed from Ni_3Al (γ‘) (**Fig. 5**). Structure of samples Ni-22Al (**Figs. 6 and 7**) contained also two-phase areas formed by nickel solid solution (γ) and Ni_3Al (γ‘), so called network structure γ/γ‘, as it was already mentioned above. Network structure, is composed of channels of nickel solid solution (γ) and smaller grains of Ni_3Al. The channels γ may contain precipitated particles γ‘ of very small dimensions.

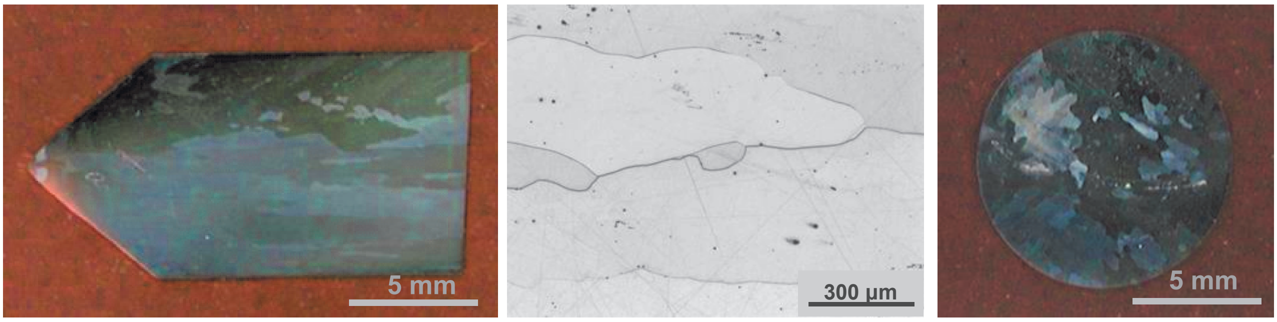

Fig. 5 Sample Ni-24Al, 50 mm/h after directional solidification, longitudinal and transverse sections

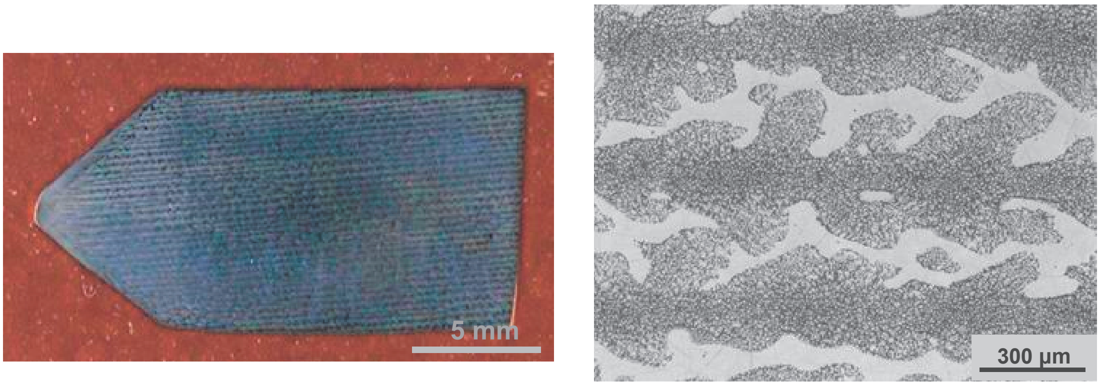

Fig. 6 Sample Ni-22Al, 50 mm/h - after directional solidification, longitudinal section

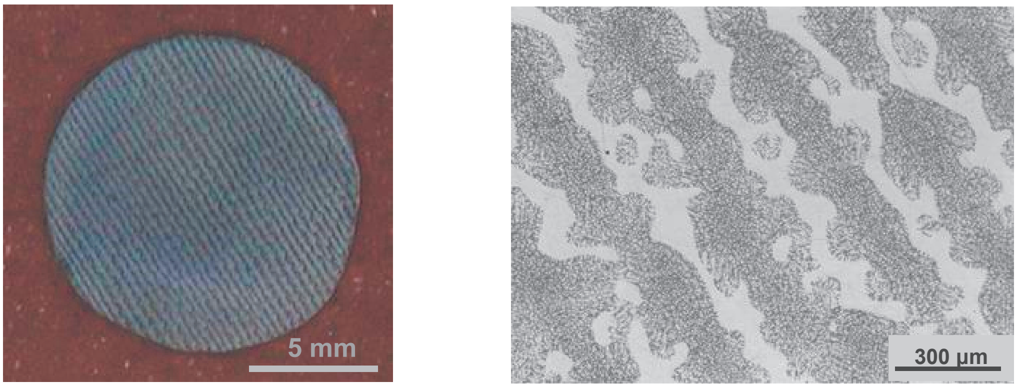

Fig. 7 Sample Ni-22Al, 50 mm/h - after directional solidification, transverse section

CONCLUSIONS

Creep characteristics of the directionally solidified Ni-24Al and Ni-22Al alloys were tested at elevated temperatures. It may be stated that the no significant adverse effect of the atmosphere was proved. No significant differences in the appearance and quantity of corrosion products on the surface of the samples were found after the creep. The Ni_3Al based alloys without alloying elements did not show any significant corrosion damage of the surface. The Ni-22Al alloy exhibits longer time to rupture than the alloy Ni-24Al under the same testing conditions. It can be seen that the multiphase structure of these alloys containing network structure of γ and γ', as well as precipitates of γ', is very favourable. Material exhibits improved mechanical properties at elevated temperatures.

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